CLAIMS

1. A filtering device for filtering signals having steep edges, comprising at least one neuro-fuzzy filter, the neuro-fuzzy filter comprising:

a signal-feature calculating unit receiving input samples of a signal to be filtered and generating signal features;

a neuro-fuzzy network receiving said signal features and generating reconstruction weights; and

a moving-average reconstruction unit receiving said input samples and said reconstruction weights, and generating output samples from said input samples and said reconstruction weights.

2. The filtering device of claim 1 wherein said signal-feature calculating unit comprises a memory storing a first plurality of input samples forming a first window, and a feature-calculating network receiving said first plurality of input samples and supplying a plurality of features for each one of said input samples.

3. The device of claim 2 wherein said feature-calculating network comprises first feature-providing means that generate, for each of said input samples, a first signal feature correlated to a position of said input sample in said first window; second feature-providing means that generate, for each of said input samples, a second signal feature correlated to the difference between said input sample and a central sample in said first window; and third feature-providing means that generate, for each of said input samples, a third signal feature correlated to the difference between said input sample and an average sample value in said first window.

4. The device of claim 3 wherein said first feature-providing means generate said first signal feature for an input sample according to the relation

$$X1(i) = \frac{|i - N|}{N}$$

wherein i is the position of said input sample in said first window, and N is the position of a central sample in said first window.

5. The device of claim 4 wherein said first feature-providing means comprise a first work memory storing said first signal feature for each one of said input samples.

6. The device of claim 3 wherein said second feature-providing means generate said second signal feature for an input sample according to the relation

$$X2(i)=\frac{|e(i)-e(N)|}{\max(diff)}$$

wherein $e(N)$ is a central sample in said first window, and max($diff$) is the maximum of the differences between all the input samples in said first window and said central sample.

7. The device of claim 3 wherein said third feature-providing means generate said third signal feature for an input sample according to the relation

$$X3(i)=\frac{|e(i)-av|}{\max(diff\_av)}$$

wherein av is the average value of the input samples in said first window, and max($diff\_av$) is the maximum of the differences between all the input samples in said first window and said average value av.

8. The device of claim 1 wherein said neuro-fuzzy network (3) comprises:

fuzzification neurons receiving said signal features of an input sample and generating first-layer outputs defining a confidenee level of said signal features with respect to preset membership functions;

fuzzy neurons of an AND type, receiving said first-layer outputs and generating second-layer outputs deriving from fuzzy rules; and

a defuzzification neuron receiving said second-layer outputs and generating a reconstruction weight for each of said input samples, using a center-of-gravity criterion.

9. The device of claim 8 wherein said membership functions are gaussian functions, and said first-layer outputs are calculated according to the equation

$$oL1(l,k) = \exp\left(-\left(\frac{Xl - W_m(l,k)}{W_v(l,k)} \right)^2 \right)$$

wherein $oL1(l, k)$ is a first-layer output, Xl is a signal feature, $W_m(l, k)$ is the mean value, and $W_v(l, k)$ is the variance of a gaussian function.

10. The filtering device of claim 8, comprising two membership functions for each one of said signal features.

11. The filtering device of claim 8 wherein said first-layer neurons comprise a second work memory storing values of said first-layer outputs for each value of said signal features.

12. The filtering device of claim 8 wherein said fuzzy rules are of an AND type, and said second-layer outputs use the norm of the minimum.

13. The filtering device of claim 12 wherein said second-layer outputs are calculated according to the equation

$$oL2(n) = \min_n \{ W_{FA}(m,n) \cdot oL1(m) \}$$

wherein $oL2(n)$ is a second-layer output; $W_{FA}(m, n)$ is a second-layer weight, and $oL1(l, k)$ is a first-layer output.

14. The filtering device of claim 13 wherein said second-layer neurons comprise a plurality of multiplication units and a plurality of minimum modules cascade-connected together.

15. The filtering device of claim 8 wherein said reconstruction weights are calculated according to the equation

$$oL3 = \frac{\sum_{n=1}^{N} W_{DF}(n) \cdot oL2(n)}{\sum_{n=1}^{N} oL2(n)}$$

wherein $oL3(n)$ is a reconstruction weight; $W_{DF}(n)$ are third-layer weights, and $oL2(n)$ is a second-layer output.

16. The filtering device of claim 8 wherein said moving-average reconstruction unit receives a second plurality of input samples forming a second window, and a corresponding plurality of reconstruction weights, and calculates each of said output samples according to the equation

$$u(i) = \frac{\sum_{j=0}^{2N} oL3(i-j) \cdot e(i-j)}{\sum_{j=0}^{2N} e(i-j)}$$

wherein $e(i-j)$ is an $(i-j)$-th input sample, and $oL3(i-j)$ is a reconstruction weight associated to an $(i-j)$-th input sample.

17. The filtering device of claim 8, comprising a training unit having a first input connected to said moving-average reconstruction unit and receiving said output samples, a second input receiving a desired output signal, and an output connected to said neuro-fuzzy network to supply optimized weighting values.

18. The filtering device of claim 2, comprising a first splitting stage generating at least two streams of samples to be filtered; one said neuro-fuzzy filter for each stream of samples to be filtered, each of said neuro-fuzzy filters generating a respective stream of filtered samples; and a first recomposition stage receiving said streams of filtered samples and generating a single stream of output samples.

19. The filtering device of claim 18, comprising a plurality of further splitting stages cascade-connected together and to said first splitting stage, and a plurality of further recomposition stages cascade-connected to each other between said neuro-fuzzy filters and said first recomposition stage.

20. The filtering device of claim 18 wherein said splitting stages each comprise a first and a second analysis filters in phase quadrature to each other and receiving a stream of samples to be split, said first and a second analysis filters generating a respected stream of split samples, and a first and a second downsampling unit, each of which receives a respective stream of split samples,

and wherein said recomposition stages each comprise a first and a second upsampling units, each first and a second upsampling units receiving a respective stream of samples to be incremented and generating a respective stream of incremented samples; a first and a second synthesis filters in quadrature with to each other and complementary to said analysis filters, each of said first and a second synthesis filters receiving a respective stream of incremented samples and generating a respective stream of partial samples; and an adder node receiving said streams of partial samples and generating a stream of added samples.

21. The filtering device of claim 20 wherein said analysis filters are quadrature mirror filters, and said synthesis filters (G_0, G_1; G_{021}-G_{102}) are QMFs complementary to said analysis filters.

22. The filtering device of claim 21 wherein said quadrature mirror filters are convolutive filters.

23. A method for reducing noise in a signal having sharp edges, comprising the steps of:

calculating signal features from input samples of a signal to be filtered;

calculating reconstruction weights from said signal features using a neuro-fuzzy network; and

reconstructing, from said input samples and said reconstruction weights and using a moving-average filter, an output signal including a plurality of output samples.

24. The method of claim 23, comprising the steps of:

storing a first plurality of input samples forming a first window; and

calculating, from said first plurality of input samples, a plurality of signal features for each of said input samples.

25. The method of claim 24 wherein said step of calculating a plurality of signal features for each of said input samples comprises the steps of:

calculating a first signal feature correlated to a position of said input sample in said first window;

calculating a second signal feature correlated to the difference between said input sample and a central sample in said first window; and

calculating a third signal feature correlated to the difference between said input sample and an average sample value *av* in said first window.

26. The method of claim 24 wherein said step of calculating reconstruction weights comprises the steps of:

performing a fuzzification operation and calculating first-layer outputs defining confidence levels of said signal features with respect to preset membership functions;

performing a fuzzy AND operation and generating second-layer outputs deriving from fuzzy rules, starting from said first-layer outputs; and

performing a defuzzification operation on said second-layer outputs and generating a reconstruction weight for each one of said input samples, using a center-of-gravity criterion of the.

27. The method of claim 26 wherein said membership functions are gaussian functions, and said first-layer outputs are calculated according to the equation

$$oL1(l,k) = \exp\left(-\left(\frac{Xl - W_m(l,k)}{W_v(l,k)}\right)^2\right)$$

wherein $oL1(l, k)$ is a first-layer output, Xl is a signal feature, $W_m(l, k)$ is the mean value, and $W_v(l, k)$ is the variance of a gaussian function.

28. The method of claim 26 wherein said second-layer outputs are calculated according to the equation

$$oL2(n) = \min_n \{W_{FA}(m,n) \cdot oL1(m)\}$$

wherein $oL2(n)$ is a second-layer output; $W_{FA}(m, n)$ is a second-layer weight, and $oL1(l, k)$ is a first-layer output.

29. The method of claim 26 wherein said reconstruction weights are calculated according to the equation

$$oL3 = \frac{\sum_{n=1}^{N} W_{DF}(n) \cdot oL2(n)}{\sum_{n=1}^{N} oL2(n)}$$

wherein $oL3$ is a reconstruction weight; $W_{DF}(n)$ are third-layer weights, and $oL2(n)$ is a second-layer output.

30. The method of claim 24, wherein said step of reconstructing using a moving-average filter comprises the steps of:

receiving a second plurality of input samples forming a second window, and a respective plurality of reconstruction weights; and

calculating each of said output samples according to the equation

$$u(i)=\frac{\sum_{j=0}^{2N} oL3(i-j)\cdot e(i-j)}{\sum_{j=0}^{2N} e(i-j)}$$

wherein $e(i-j)$ is an $(i-j)$-th input sample, and $oL3(i-j)$ is a reconstruction weight associated to an $(i-j)$-th input sample.

31. The method of claim 23, comprising a training step for training weights used in said neuro-fuzzy filtering step.

32. The method of claim 31 wherein said training step comprises the steps of:

generating an input signal having a known configuration;

filtering said input signal having a known configuration to obtain a test output signal;

comparing said test output signal with a desired signal to obtain a distance between said test output signal and said desired signal;

calculating a fitness function from said distance; and

optimizing said weights in accordance with said fitness function.

33. The method of claim 24, comprising a multiresolution analysis whereby the signal is split into sub-bands through orthonormal wavelets.

34. The method of claim 33, comprising the steps of:

splitting a stream of input samples into at least two streams of samples to be filtered;

filtering each stream of samples to be filtered using a respective neuro-fuzzy filter to obtain at least two streams of filtered samples; and

recomposing said streams of filtered samples to generate a single stream of output samples.

35. The method of claim 34 wherein, before performing said step of filtering, said step of splitting is repeated a preset number of times, and in that, after performing said step of filtering, said step of recomposing is repeated said preset number of times.

36. The method of claim 34 wherein said step of splitting comprises the steps of:

feeding a stream of samples to be split to two analysis filters in phase quadrature to each other;

generating two streams of filtered split samples; and

downsampling said streams of filtered split samples,

and in that said step of recomposing comprises the steps of:

upsampling streams of samples to be incremented, generating streams of incremented samples;

filtering said streams of incremented samples using two synthesis filters in phase quadrature to each other and complementary to said analysis filters, generating streams of partial samples; and

adding pairs of streams of partial samples and generating a stream of added samples.

37. A filtering device for filtering signals, comprising:

a signal-feature calculating circuit configured to receive input samples of a signal to be filtered and to generate signal features therefrom;

a neuro-fuzzy network circuit coupled to the signal-feature calculating circuit and configured to receive the signal features and to generate reconstruction weight signals therefrom;

a moving-average reconstruction circuit coupled to the neuro-fuzzy network circuit and configured to receive the input samples and the reconstruction weight signals and to generate therefrom output samples; and

a training circuit having a first input coupled to the moving-average reconstruction circuit for receiving the output samples, a second input for receiving a desired output signal, and an output coupled to the neuro-fuzzy network circuit, the training unit configured to supply on the output optimized weighting value signals.

38. A filtering device for filtering signals, comprising:

a signal-feature calculating circuit configured to receive input samples of a signal to be filtered and to generate signal features therefrom;

a neuro-fuzzy network circuit coupled to the signal-feature calculating circuit and configured to receive the signal features and to generate reconstruction weight signals therefrom;

a moving-average reconstruction circuit coupled to the neuro-fuzzy network circuit and configured to receive the input samples and the reconstruction weight signals and to generate therefrom output samples, the neuro-fuzzy network circuit comprising fuzzification neurons receiving the signal features of the input sample and configured to generate first-layer outputs defining a confidence level of the signal features with respect to preset membership functions, fuzzy neurons of an AND type receiving the first layer outputs and configured to generate second-layer outputs derived from fuzzy rules, and a defuzzification neuron receiving the second-layer outputs and configured to generate a reconstruction weight signal for each of the input samples using a center-of-gravity criterion; and

a training circuit having a first input coupled to the moving-average reconstruction circuit for receiving the output samples, a second input for receiving a desired output signal, and

an output coupled to the neuro-fuzzy network circuit, the training unit configured to supply on the output optimized weighting value signals.

39. A filtering device, comprising:

a first splitting stage receiving input samples of a signal to be filtered and generating at least two streams of samples to be filtered;

a neuro-fuzzy filter for each stream of samples to be filtered, each neuro-fuzzy filter generating a respective stream of filtered samples and comprising:

a signal-feature calculating circuit receiving one of the at least two streams of samples to be filtered and configured to generate signal features therefrom;

a neuro-fuzzy network circuit coupled to the signal-feature calculating circuit and configured to receive the signal features and to generate reconstruction weight signals therefrom; and

a moving-average reconstruction circuit receiving the input samples and the reconstruction weight signals and generating output samples therefrom; and

a first recomposition stage receiving a stream of filtered samples from each neuro-fuzzy filter and generating therefrom a single stream of output samples.

40. A filtering device, comprising:

a first splitting stage receiving input samples of a signal to be filtered and generating at least two streams of samples to be filtered;

a neuro-fuzzy filter for each stream of samples to be filtered, each neuro-fuzzy filter generating a respective stream of filtered samples and comprising:

a signal-feature calculating circuit receiving one of the at least streams of samples to be filtered and configured to generate signal features therefrom;

a neuro-fuzzy network circuit coupled to the signal-feature calculating circuit and configured to receive the signal features and to generate reconstruction weight signals therefrom;

a moving-average reconstruction circuit receiving the input samples and the reconstruction weight signals and generating output samples therefrom; and

a training circuit having a first input coupled to the moving-average reconstruction circuit and receiving the output samples, a second input receiving a desired output signal, and an output coupled to the neuro-fuzzy network circuit and configured to supply optimized weighting value signals thereto; and

a first recomposition stage receiving a stream of filtered samples from each neuro-fuzzy filter and generating therefrom a single stream of output samples.